I. Infrared-Based Temperature Measurement in Diesel Exhaust Aftertreatment Filters

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Objectives

- Develop a fiber optic system for non-contact, in-situ temperature measurement in diesel exhaust aftertreatment filters.
- Establish calibration methods for the fiber optic temperature measurement system.
- Measure the temperature distribution in diesel exhaust aftertreatment filters during microwave heating.

Approach

- Use infrared thermometry to select suitable optical fiber and infrared sensors as well as the system configuration for the application.
- Perform component tests and blackbody calibration to determine characteristics of the fiber optic temperature measurement system.
- Validate the fiber optic system configurations in microwave-heated diesel particulate filters (DPFs).
- Conduct the temperature measurement testing and analyze the results.

Accomplishments

- Developed a fiber optic radiation thermometry system to measure the inner wall surface temperature in a diesel exhaust aftertreatment filter.
- Demonstrated the system’s capability to measure temperatures ranging from 100 to 400°C in the filter channel with large aspect ratio.
- Applied a sapphire fiber with a 45° angled tip to measure the thermal radiation from a small and specific region on the inner filter wall surface perpendicular to the fiber axis.

- Using both one-color and two-color thermometry methods, found a small temperature discrepancy for channels with large aspect ratio or near blackbody characteristics.
- Used a multi-channel infrared fiber optic system to study the temperature distribution during microwave regenerative heating of DPFs.
- Tested temperature distribution of DPFs with different levels of soot and catalyst.

Future Direction

- Implement this technology in an operating diesel exhaust aftertreatment filter with exhaust flow, soot deposition, and catalysts. Provide the data for study of nitrogen oxide (NO_x) and particulate filter reliability and durability, thermal cycle fatigue, and modeling of the regenerative temperature distribution.

Introduction

The accurate, in-situ measurement of filter surface temperature is important for the development of diesel exhaust aftertreatment techniques. The temperature on inner filter wall surfaces controls the chemical kinetics of the storage and regeneration of NO_x and particulate matter. New catalytic technologies have been applied to lower the regeneration temperature, which is beneficial for engine fuel efficiency. To study the effectiveness of new catalysts and their effects on the storage and regeneration process, accurate filter wall temperature data are required. A uniform temperature distribution in the filter is important to control the homogeneous chemical reactions as well as avoid overheating and thermal stress fatigue.

Diesel exhaust aftertreatment filters are typically made of porous ceramic material with deep channels to increase the specific surface area. Attaching thermocouples to the filter wall surface at locations deep within the filter channel has proved difficult because of the space constraints. As an alternative to using a thermocouple, an optical fiber can be employed to transmit the emitted surface thermal radiation to an infrared detector for temperature measurement. Using an optical fiber with a 45° angled tip, the field of view of the fiber tip can be narrowed to a small and specific region on the filter wall surface. Precise thermal mapping of the filter is achieved by measuring the surface temperature at various locations inside filter channels.

Approach

Two radiation thermometry systems were developed that use optical fibers to transmit the emitted surface thermal radiation in the channels of the diesel exhaust aftertreatment filter to outside infrared detectors.

The first system consists of a sapphire fiber with a 45° angled tip, the lead sulfide/lead selenide (PbS/PbSe) two-color sensor, and a data conditioning and acquisition device, as shown in Figure 1. Based on two wide-band infrared PbS and PbSe detectors, the system is able to measure temperatures ranging from 100 to 400°C, the regeneration temperature for catalyzed filters. As shown in Figure 2, the PbS and PbSe detectors are sensitive to infrared radiation from 1.0 to 2.8 μm and from 2.8 to 4.5 μm wavelength, with peaks at 2.5 and 3.7 μm, respectively. Both PbS and PbSe detectors have a broad-spectrum range of detection of about 1.8 μm. Since PbS and PbSe are photoconductors sensitive only to an ac signal, a mechanical chopper (Figure 1) was used in front of the sensor's connection to the optical fiber to generate an ac light signal input. The PbS/PbSe two-color sensor has a sandwiched construction. Only one infrared input is required for this sensor. It has eliminated the need to split the light to

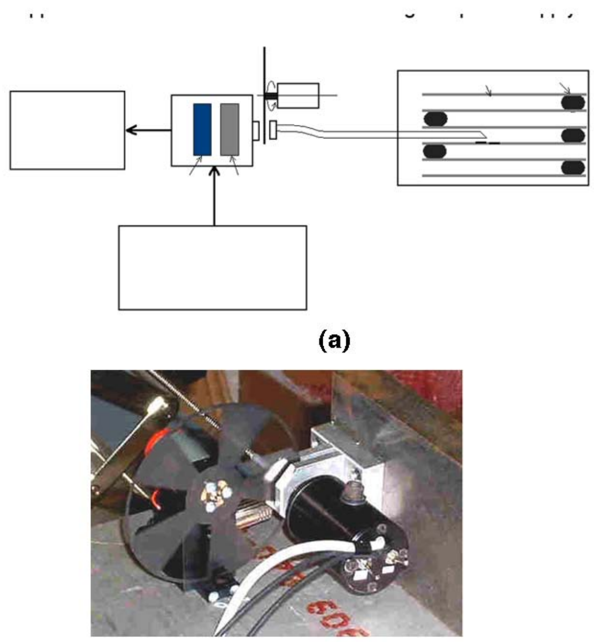

Figure 1. The application of PbS/PbSe two-color sensor and sapphire optical fiber for measurement of diesel exhaust aftertreatment filter temperature; (a) experiment setup and (b) close-up view of the two-color sensor, chopper, and sapphire fiber.

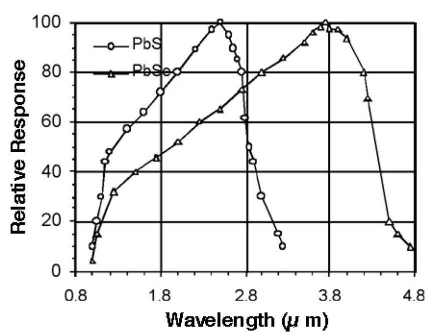

Figure 2. The relative response of the detectors vs wavelength.

two infrared detectors. As illustrated in Figure 1(a), the PbS detector is placed in front of the PbSe detector to receive the thermal radiation from the optical fiber. By employing a sapphire fiber with a 45° angled tip, the thermal radiation from a small and specific region opposite the polished tip face and perpendicular to the fiber axis is measured. The goniometric characteristics of this fiber tip geometry were studied using the angular scan method when the 45° angled tip fiber was used inside a channel in the DPF. The fiber tip collects most of the thermal radiation from the filter wall surface at point A in Figure 1a. A small portion of thermal radiation at point B in front of the fiber tip is also transmitted to the infrared sensor.

The second radiation thermometry system was developed in collaboration with Cummins Technical Center. A multi-channel fiber optic infrared system (Figure 3) was developed to measure the temperature

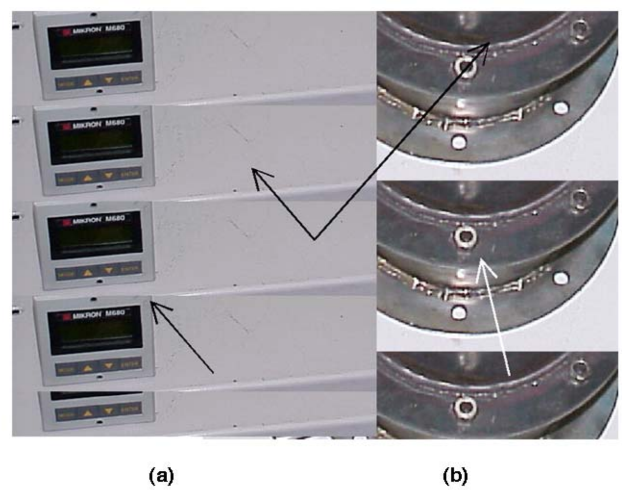

Figure 3. Setup for microwave heating temperature measurement (a) thermometers and transmission fibers and (b) close-up view of the silica light-pipes insertion.

distribution of diesel exhaust aftertreatment filters. The system uses multiple silica light-pipes to collect the infrared radiation from different locations inside a filter to study the temperature distribution during microwave regenerative heating of the DPF.

The sensing material used in this system is InGaS, which provides good sensitivity to near-infrared radiation in a spectral band of 1.0 to 1.6 μm. The system is able to measure temperature from 150 to 1000°C, which makes it suitable for the observation of a wide temperature variation due to exothermic reaction in the DPF regeneration process. DPFs with different levels of soot and catalyst were tested. Temperature measurements were performed at 36 locations on each DPF, and the temporal and spatial temperature distribution on each DPF during a 10-min microwave heating period was obtained.

Results

Both one-color and two-color thermometry methods were implemented in the first system setup. Figure 4 shows the system calibration curves of the one-color and two-color methods against a blackbody heat source. The wall surface temperature of a microwave-heated ceramic filter was measured at four locations. The discrepancy between the two temperature measurement methods was small for the channel with large aspect ratio or near blackbody characteristics, marked by locations IC and IS in Figure 5.

Three advanced wall-flow DPFs were tested by the integration of the multi-channel fiber optic temperature measurement system with a bench-scale microwave heating system. These DPFs are the uncatalyzed filter with soot loading, catalyzed filter without soot loading, and catalyzed filter with soot loading. Experimental results show non-uniform heating across the filter. The measured temperature distributions are used to verify numerical modeling results. The interaction between catalyst, soot, and microwave power changes the heating pattern as well as the temperature distribution. During a 10-min heating period, a 1-kW microwave power setting was able to raise the temperatures above 200°C in most areas of a catalyzed filter with soot loading.

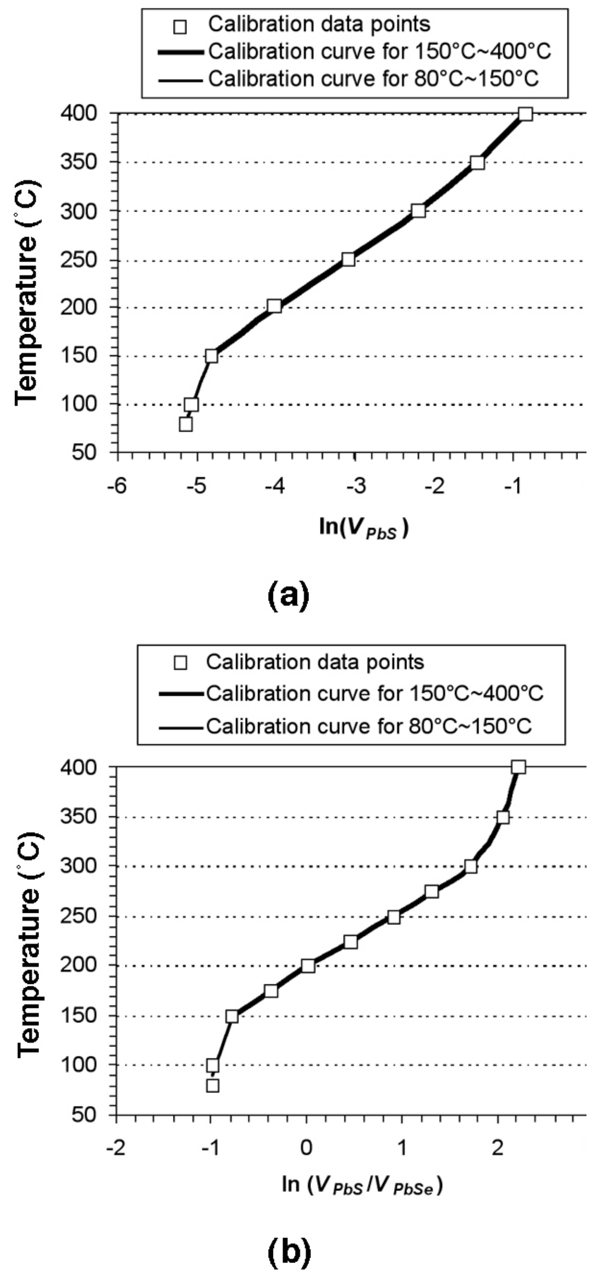

Figure 4. Blackbody calibration results: (a) one-color calibration data points and curves and (b) two-color calibration data points and curves.

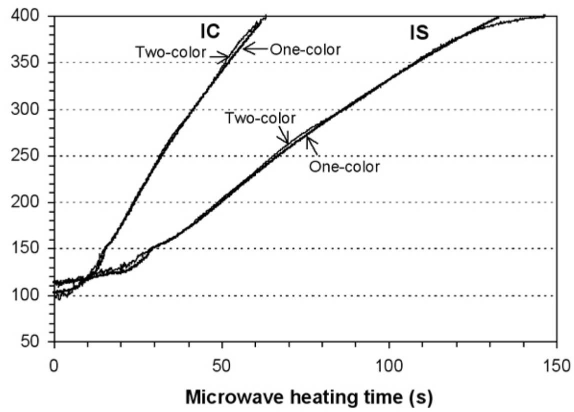

Figure 5. Temperature history reported by both the one-color and two-color methods in the filter channel with large aspect ratios.

Conclusions

Fiber optic radiation thermometry systems were developed to measure the channel wall surface temperature in diesel exhaust aftertreatment filters. Experimental results show that the system is suitable for noncontact, in-situ temperature measurement at a specific region within the channel of diesel exhaust aftertreatment filters. Results of the temporal and spatial temperature distribution on DPFs with different levels of soot and catalyst lead to a better understanding of the diesel exhaust aftertreatment regeneration mechanism and process and provide important data for the study of NO_x and particulate filter reliability and durability, thermal cycle fatigue, and modeling of the regenerative temperature distribution.

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Publications

B. J. Boothe, A. J. Shih, J. Kong, and W L. Roberts, “Goniometric Characteristics of Optical Fibres for Temperature Measurement in Diesel Engine Exhaust Filters,” *Measurement Science and Technology*, **14**(5), 563–572, (2003).

A. C. Curry, A. J. Shih, R. O. Scattergood, J. Kong, and S. B. McSpadden, “Grinding Temperature Measurements in MgO PSZ Using Infrared Spectrometry,” *J. Am. Ceram. Soc.*, **86**, 333–341, (2003).

J. Kong and A. J. Shih, “Infrared Thermometry for Diesel Exhaust Aftertreatment Filter Temperature Measurement,” *SAE Transactions* (submitted).

J. Kong, M. Bakkal, S. F. Miller, and A. J. Shih, “Temperature Measurement in Ceramic Grinding, Machining of Bulk Metallic Glass, and Electrical Discharge Machining,” pp. 415–424 in *Proceedings of the National Science Foundation Workshop on Research Needs in Thermal Aspects of Material Removal Processes*, Stillwater, OK, June 2003.

J. Kong, A. J. Shih, R. O. Scattergood, T. M. Yonushonis, D. J. Gust, M. B. Grant, and S. B. McSpadden, “Cost-Effective Form Grinding of Zirconia using Silicon Carbide Wheels and Ceramic Grinding Temperature Measurement,” presented at the National Science Foundation Design, Service and Manufacturing Grantees and Research Conference, January 6–9, 2003, Birmingham, Alabama.